EXHIBIT A

CERTIFICATE OF VERIFICATION

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state that the attached documents are a true and complete translation to the best of my knowledge of Japanese Patent Application No. 083135/2001.

Dated this 2nd day of March, 2004

Signature of translator:
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PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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[Name of Document] Specification

[Title of the Invention] Raman Amplification Optical Fiber, Optical Fiber Coil, Raman Amplifier, and Optical Communication System

[Claims]

[Claim 1] A Raman amplification optical fiber for Raman-amplifying signal light when Raman amplification pumping light is supplied thereto, said Raman amplification optical fiber, at a wavelength of said signal light, having:

a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less;

an effective area A_{eff} of 20 μm^2 or less; and

a Raman gain coefficient G_R/A_{eff} of 0.005 $(W \cdot m)^{-1}$ or more.

[Claim 2] A Raman amplification optical fiber for transmitting signal light and Raman-amplifying said signal light when Raman amplification pumping light is supplied thereto; said Raman amplification optical fiber, at a wavelength of said signal light, having:

a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less; and

an effective area A_{eff} of less than 15 μm^2.

[Claim 3] An optical fiber coil including the Raman amplification optical fiber according to claim 1 or 2 wound in a stacked fashion.

[Claim 4] A Raman amplifier for Raman-amplifying signal light introduced from an input end thereof and outputting thus amplified signal light from an output end thereof, said Raman amplifier comprising:

the Raman amplification optical fiber according to claim 1 or 2, said Raman amplification optical fiber being disposed

on at least part of a transmission line between said input end and said output end; and

a pumping light supplier supplying said Raman amplification pumping light to said Raman amplification optical fiber.

[Claim 5] A Raman amplifier according to claim 4, wherein cumulative chromatic dispersion from said input end to said output end has an absolute value of 100 ps/nm or less at the wavelength of said signal light.

[Claim 6] An optical communication system transmitting said signal light and Raman-amplifying said signal light by the Raman amplifier according to claim 4.

[Claim 7] An optical communication system according to claim 6, wherein the wavelength of said signal light exists within C band (1530 nm to 1565 nm).

[Claim 8] An optical communication system according to claim 6, wherein the wavelength of said signal light exists within L band (1565 nm to 1625 nm).

[Claim 9] An optical communication system according to claim 6, wherein the wavelength of said signal light exists within S band (1460 nm to 1530 nm).

[Detailed Description of the Invention]

[0001]

[Technical Field of Utilization]

The present invention relates to a Raman amplification optical fiber which Raman-amplifies signal light when Raman amplification pumping light is supplied thereto, a Raman amplifier including the Raman amplification optical fiber, an optical fiber coil in which the Raman amplification optical fiber is wound in a stacked fashion, and an optical communication

system including the Raman amplifier.

[0002]

[Prior Art]

Raman amplifiers are those containing a Raman amplification optical fiber as an optical amplifier medium, thus being able to Raman-amplify signal light when Raman amplification pumping light is supplied to the Raman amplification optical fiber, and utilizes Raman shift which is a kind of nonlinear optical phenomenon in the Raman amplification optical fiber. From this viewpoint, it is desirable for the Raman amplification optical fiber to have a high nonlinearity. For example, the Raman amplifier disclosed in Japanese Patent Application Laid-Open No. HEI 11-84440 utilizes a highly nonlinear optical fiber or dispersion-compensating optical fiber as a Raman amplification optical fiber, so as to carry out lumped optical amplification.

[0003]

[Problems that the Invention is to Solve]

When a highly nonlinear optical fiber is utilized as a Raman amplification optical fiber, the Raman amplification efficiency becomes higher, whereby a large Raman amplification gain can be obtained, or a sufficient Raman amplification gain can be obtained at a relatively short fiber length. However, since the highly nonlinear optical fiber has a high nonlinearity at a signal wavelength, the waveform of signal light may deteriorate under the influence of nonlinear optical phenomena such as four-wave mixing.

[0004]

When a dispersion-compensating optical fiber is utilized as the Raman amplification optical fiber, on the other hand, it

not only amplifies the signal light but also can compensate for the chromatic dispersion of the optical fiber transmission line. Additionally, since the chromatic dispersion of the dispersion-compensating optical fiber has a large absolute value at the signal wavelength, the signal waveform is effectively restrained from deteriorating due to the four-wave mixing in the dispersion-compensating optical fiber. However, since the chromatic dispersion of dispersion-compensating optical fiber has a large absolute value at the signal wavelength, it is necessary that the length of the dispersion-compensating optical fiber be controlled strictly according to the length of the optical fiber transmission line, whereby the degree of freedom in the design of optical fiber transmission lines or the design of Raman amplifiers is small.

[0005]

In order to overcome the above-mentioned problems, it is an object of the present invention to provide a Raman amplification optical fiber which can Raman-amplify signal light at a high efficiency and effectively restrain signal waveforms from deteriorating due to influences of nonlinear optical phenomena, while improving the degree of freedom in the design of optical fiber transmission lines and Raman amplifiers. It is another object of the present invention to provide a Raman amplifier including the above-mentioned Raman amplification optical fiber, an optical fiber coil in which the Raman amplification optical fiber is wound in a stacked fashion, and an optical communication system including the Raman amplifier.

[0006]

[Means for Solving the Problems]

A Raman amplification optical fiber according to the

present invention Raman-amplifies signal light when Raman amplification pumping light is supplied thereto, and is characterized by having, at a wavelength of signal light, a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, an effective area A_{eff} of 20 μm^2 or less, and a Raman gain coefficient G_R/A_{eff} of 0.005 $(W \cdot m)^{-1}$ or more. Or, the Raman amplification optical fiber is characterized by having, at the wavelength of signal light, a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, and an effective area A_{eff} of less than 15 μm^2. By setting the effective area or Raman gain coefficient within its corresponding range mentioned above, the Raman amplification optical fiber enables the Raman amplification of signal light at a high efficiency. Additionally, by setting the absolute value of chromatic dispersion as a characteristic at the wavelength of signal light within the above-mentioned range, the Raman amplification optical fiber can effectively restrain signal waveforms from deteriorating due to influences of nonlinear optical phenomena, thereby improving the degree of freedom in the design of optical fiber transmission lines or Raman amplifiers.

[0007]

The optical fiber coil according to the present invention is characterized by the above-mentioned Raman amplification optical fiber according to the present invention wound in a stacked fashion. When such an optical fiber coil is employed, a lumped Raman amplifier can be realized.

[0008]

The Raman amplifier according to the present invention Raman-amplifies signal light introduced from an input end

thereof and outputs thus amplified signal light from an output end thereof, and is characterized by comprising the above-mentioned Raman amplification optical fiber according to the present invention disposed on at least a part of a transmission line between the input end and the output end, and a pumping light supplier supplying the Raman-amplification pumping light into the Raman amplification optical fiber. Preferably, in the Raman amplifier, cumulative chromatic dispersion from the input end to the output end has an absolute value of 100 ps/nm or less at the wavelength of signal light. Since the Raman amplifier employs the Raman amplification optical fiber according to the present invention, it can yield a high Raman amplification gain and effectively suppress the deterioration in signal waveforms, and additionally has a high degree of freedom in design. In particular, for suppressing the deterioration in signal waveforms, it will be more favorable if the cumulative chromatic dispersion of the Raman amplification optical fiber has an absolute value of 100 ps/nm or less.

[0009]

The optical communication system according to the present invention is characterized by transmitting the signal light, and Raman-amplifying the signal light by the Raman amplifier according to the present invention. Preferably, one of the wavelength of signal light in the optical communication system falls within one of C-band (1530 nm to 1565 nm), L-band (1565 nm to 1625 nm), and S-band (1460 nm to 1530 nm). The optical communication system, by employing the Raman amplifier according to the present invention, makes it possible to transmit signal light over a long haul, effectively suppresses the deterioration in signal waveforms, and yields a high degree

of freedom in design.

[0010]

[Embodiments of the Invention]

In the following, embodiments of the present invention with reference to the attached figures. In the explanation of the drawings, constituents identical to each other will be referred to with numerals identical to each other without repeating their overlapping descriptions.

[0011]

(First Embodiment)

First, a first embodiment of each of a Raman amplification optical fiber, an optical fiber coil, a Raman amplifier and an optical communication system according to the present invention will be explained.

[0012]

Fig. 1 is a view showing a refractive index profile of the Raman amplification optical fiber 100 according to the first embodiment. The Raman amplification optical fiber 100 according to the present embodiment a silica glass-based one includes a core region which includes an optical axis center, has an outer diameter of 2a and is doped with GeO_2, a first cladding region which surrounds the core region, has an outer diameter of 2b and is doped with F element, and a second cladding region surrounding the first cladding region.

[0013]

At the wavelength of signal light, the Raman amplification optical fiber 100 has a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, an effective area A_{eff} of 20 μm^2 or less , and a Raman gain coefficient G_R/A_{eff} of 0.005 $(W\cdot m)^{-1}$ or more. Or, the Raman amplification optical

fiber 100 has a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, and an effective area A_{eff} of less than 15 μm^2. Here, the wavelength of signal light falls within one of C-band, L-band, and S-band.

[0014]

The Raman amplification optical fiber 100 can Raman-amplify the signal light at a high efficiency since it has the effective area and Raman gain coefficient falling within their respective ranges mentioned above. Also, since the absolute value of chromatic dispersion at the wavelength of signal light falls within its range mentioned above, signal waveforms are effectively restrained from deteriorating due to influences of nonlinear optical phenomena, whereby the degree of freedom improves in the design of optical fiber transmission lines and Raman amplifiers.

[0015]

Fig. 2 is a view showing a configuration of a Raman amplifier 10 according to the first embodiment. The Raman amplifier 10 according to the present embodiment comprises an optical fiber coil 110 in which the Raman amplification optical fiber 100 is wound in a stacked fashion, and a pumping light source 120 for outputting Raman amplification pumping light to be supplied to the optical fiber coil 110. This figure also illustrates a signal light source 130 for outputting the signal light to be fed into the Raman amplifier 10, and an optical spectrum analyzer 140 for measuring the spectrum of signal light outputted from the Raman amplifier 10.

[0016]

In the Raman amplifier 10, the Raman amplification pumping light outputted from the pumping light source 120 is supplied

to the optical fiber coil 110. The signal light outputted from the signal light source 130 propagates through the optical fiber coil 110, and is Raman-amplified during the propagation. The Raman-amplified signal light reaches the optical spectrum analyzer 140, and its spectrum is measured by the optical spectrum analyzer 140.

[0017]

The Raman amplifier 10 employs the Raman amplification optical fiber 100 according to the present embodiment, and thereby obtaining a high gain in Raman amplification, restraining the deterioration in signal waveforms, and obtaining a high degree of freedom in design. In particular, for suppressing the deterioration in signal waveforms, it will be more favorable if the cumulative chromatic dispersion of the Raman amplification optical fiber has an absolute value of 100 ps/nm or less.

[0018]

Next, a specific example according to the present embodiment will be explained. In the Raman amplification optical fiber 100, the outer diameter 2a of the core region is 3.5 μm, the outer diameter 2b of the first cladding region is 8.8 μm, the outer diameter of the second cladding region is 125 μm, a relative refractive index difference Δ^+ of the core region with respect to the second cladding region is 3.35%, and a relative refractive index difference Δ^- of the first cladding region with respect to the second cladding region is -0.35%. The Raman amplification optical fiber 100, at a wavelength of 1550 nm in C-band, exhibits a transmission loss of 0.53 dB/km, an effective area A_{eff} of 9.4 μm^2, a chromatic dispersion of -6 ps/nm/km, and a dispersion slope of +0.02 $ps/nm^2/km$. And, the

optical fiber coil 110, when Raman amplification pumping light having a wavelength of 1450 nm is supplied thereto, has a Raman gain coefficient G_R/A_{eff} is 0.0071 $(W \cdot m)^{-1}$.

[0019]

The optical fiber coil 110 is constituted by 2.1 km of the Raman optical fiber 100 wound about the reel 111 in a stacked fashion. The Raman amplification pumping light outputted from the pumping light source 120 has a wavelength of 1450 nm, whereas its power is 300 mW when fed into the optical fiber coil 110. The wavelength of signal light outputted from the signal light source 130 is 1550 nm. At this time, the Raman amplification gain of the Raman amplifier 10 is 10 dB at a wavelength of 1550 nm.

[0020]

In this example, the chromatic dispersion of the whole Raman amplifier 10 (i.e., the cumulative chromatic dispersion in the Raman amplification optical fiber 100) is -12.6 ps/nm at a signal light wavelength of 1550 nm, thus yielding a small absolute value. Therefore, in an optical communication system including the Raman amplifier 10, the contribution of the chromatic dispersion in the Raman amplification optical fiber 100 with respect to the whole optical fiber transmission line is small, whereby a degree of freedom in the design of chromatic dispersion is high. Also, the chromatic dispersion of the Raman amplification optical fiber 100 is -6 ps/nm/km at a signal light wavelength of 1550 nm, thus yielding a large absolute value. Accordingly, four-wave mixing is restrained from occurring in the Raman amplification optical fiber 100, whereby the deterioration in signal waveforms is suppressed.

[0021]

(Second Embodiment)

Next, a second embodiment of each of a Raman amplification optical fiber, an optical fiber coil, a Raman amplifier and an optical communication system according to the present invention will be explained. Fig. 3 is a view showing a configuration of an optical communication system 1 according to the second embodiment. The optical communication system 1 according to the present embodiment comprises the Raman amplifier 10, a transmitter 20, and a receiver 30, whereas an optical fiber transmission line 40 is laid between the transmitter 20 and the Raman amplifier 10.

[0022]

In this embodiment, the transmitter 20 contains an S-band signal light source 21 for outputting signal light having a wavelength within S-band, a C-band signal light source 22 for outputting signal light having a wavelength within C-band, an L-band signal light source 23 for outputting signal light having a wavelength within L-band, and a signal light multiplexer 24. The signal light multiplexer 24 multiplexes the signal light outputted from the S-band signal light source 21, the signal light outputted from the C-band signal light source 22, and the signal light outputted from the L-band signal light source 23, and sends thus multiplexed signal light to the optical fiber transmission line 40.

[0023]

The Raman amplifier 10 contains an S-band pumping light source 121, a C-band pumping light source 122, an L-band pumping light source 123, and a pumping light multiplexer 124. The S-band pumping light source 121 outputs Raman amplification pumping light having a wavelength which can Raman-amplify the

signal light outputted from the S-band signal light source 21. The C-band pumping light source 122 outputs Raman amplification pumping light having a wavelength which can Raman-amplify the signal light outputted from the C-band signal light source 22. The L-band pumping light source 123 outputs Raman amplification pumping light having a wavelength which can Raman-amplify the signal light outputted from the L-band signal light source 23. The pumping light multiplexer 124 multiplexes the Raman amplification pumping light outputted from the S-band pumping light source 121, the Raman amplification pumping light outputted from the C-band pumping light source 122, and the Raman amplification pumping light outputted from the L-band pumping light source 123, and sends thus multiplexed Raman amplification pumping light to the optical fiber coil 110.

[0024]

The optical fiber coil 110 is constituted by the Raman amplification optical fiber 100 wound in a stacked fashion. The Raman amplification optical fiber 100 has, at each wavelength of signal light, a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, an effective area A_{eff} of 20 μm^2 or less, and a Raman gain coefficient G_R/A_{eff} of 0.005 $(W \cdot m)^{-1}$ or more. Or the Raman amplification optical fiber 100 has, at each wavelength of signal light, a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, and an effective area A_{eff} of less than 15 μm^2.

[0025]

In this optical communication system 1, the Raman amplification pumping light outputted from the S-band pumping light source 121, the Raman amplification pumping light outputted from the C-band pumping light source 122, and the Raman

amplification pumping light outputted from the L-band pumping light source 123 are multiplexed by the pumping light multiplexer 124, and thus multiplexed Raman amplification pumping light is supplied to the optical fiber coil 110. The signal light outputted from the S-band signal light source 21, the signal light outputted from the C-band signal light source 22, and the signal light outputted from the L-band signal light source 23 are multiplexed by the signal light multiplexer 24, and thus multiplexed signal light is sent to the optical fiber transmission line 40. The signal light reaches the Raman amplifier 10 after propagating through the optical fiber transmission line 40, and is Raman-amplified while propagating through the optical fiber coil 110 within the Raman amplifier 10. Thereafter, the Raman-amplified signal light is received by the receiver 30. Thus, the optical communication system 1 can perform wavelength division multiplexing (WDM) transmission by using each of the signal light in S-band, signal light in C-band, and signal light in L-band, thereby enabling large-capacity, long-haul information transmission.

[0026]

Since the Raman amplifier 10 employs the Raman amplification optical fiber 100, it can exhibit a high gain in Raman amplification, can suppress the deterioration in signal waveforms, and can obtain a high degree of freedom in design. In particular, for suppressing the deterioration in signal waveforms, it will be more favorable if the cumulative chromatic dispersion of the Raman amplification optical fiber 100 has an absolute value of 100 ps/nm or less. Since the optical communication system 1 employs such a Raman amplifier 10, it enables long-haul transmission of signal light, suppresses the

deterioration in signal waveforms, and has a high degree of freedom in design.

[0027]

Next, a specific example of the above-mentioned present embodiment will be explained. The Raman amplification optical fiber 100 has the same refractive index profile as one shown in Fig. 1, whereas an outer diameter 2a of the core region is 3.9 µm, an outer diameter 2b of the first cladding region is 9.8 µm, an outer diameter of the second cladding region is 125 µm, a relative refractive index difference Δ^+ of the core region with respect to the second cladding region is 3.35%, and a relative refractive index difference Δ^- of the first cladding region with respect to the second cladding region is -0.35%. The Raman amplification optical fiber 100 has, at a wavelength of 1480 nm within S-band, a transmission loss of 0.65 dB/km, an effective area A_{eff} of 8.4 µm^2, a chromatic dispersion of -19.0 ps/nm/km, and a dispersion slope of +0.004 ps/nm^2/km. At a wavelength of 1550 nm within C-band, a transmission loss is 0.55 dB/km, an effective area A_{eff} is 9.0 µm^2, a chromatic dispersion is -18.7 ps/nm/km, and a dispersion slope is +0.004 ps/nm^2/km. At a wavelength of 1610 nm within L-band, a transmission loss is 0.52 dB/km, an effective area A_{eff} is 9.5 µm^2, a chromatic dispersion is -18.5 ps/nm/km, and a dispersion slope is +0.004 ps/nm^2/km.

[0028]

The chromatic dispersion of the whole Raman amplifier 10, i.e., the cumulative chromatic dispersion in the Raman amplification optical fiber 100, has a small absolute value at a signal light wavelength of 1550 nm in this specific example as well. Therefore, in the optical communication system 1 including the Raman amplifier 10, the contribution of the

chromatic dispersion in the Raman amplification optical fiber 100 with respect to the optical fiber transmission line 40 is small, thereby yielding a high degree of freedom in the design of chromatic dispersion. Also, the chromatic dispersion of the Raman amplification optical fiber 100 has a large absolute value at a signal light wavelength of 1550 nm. As a consequence, four-wave mixing is restrained from occurring in the Raman amplification optical fiber 100, whereby the deterioration in signal waveforms is effectively suppressed.

[0029]

Though Fig. 3 shows the S-band signal light source 21, the C-band signal light source 22, and the L-band signal light source 23 one by one, each signal light source may be constituted by a plurality of light sources having output wavelengths different from each other. Though the S-band pumping light source 121, the C-band pumping light source 122, and the L-band pumping light source 123 are shown one by one, each pumping light source may be constituted by a plurality of light sources having output wavelengths different from each other. Additionally, a plurality of transmission units each having the structure similar to that of the optical fiber transmission line 40 and Raman amplifier 10 may be provided between the transmitter 20 and the receiver 30.

[0030]

[Effects of the Invention]

As explained in the foregoing, the Raman amplification optical fiber according to the present invention has the absolute value of chromatic dispersion, the effective area A_{eff}, and the Raman gain coefficient G_R/A_{eff}, set within appropriate numeric ranges, which enables the Raman amplification of signal

light at a high efficiency, can restrain the signal waveforms from deteriorating due to influences of nonlinear optical phenomena, and can improve the degree of freedom in the design of optical fiber transmission lines and Raman amplifiers. Additionally, by utilizing the optical fiber coil in which the Raman amplification optical fiber wound in a stacked fashion, a lumped Raman amplifier can be realized.

[0031]

Since the Raman amplifier according to the present invention employs the Raman amplification optical fiber according to the present invention, it can obtain a high Raman amplification gain, can suppress the deterioration in signal waveforms, and can obtain a high degree of freedom in design. In particular, for suppressing the deterioration in signal waveforms, it will be more favorable if the cumulative chromatic dispersion in the Raman amplification optical fiber has an absolute value of 100 ps/nm or less. Also, since the optical communication system according to the present invention employs the Raman amplifier according to the present invention, it enables long-haul information transmission, can suppress the deterioration in signal waveforms, and can obtain a high degree of freedom in design.

[Brief Description of the Drawings]

[Fig. 1] It is a view showing a refractive index profile of a Raman amplification optical fiber according to the first embodiment.

[Fig. 2] It is a view showing a configuration of a Raman amplifier according to the first embodiment.

[Fig. 3] It is a view showing a configuration of an optical communication system according to the second embodiment.

[Description of the Reference Numerals]

1 ··· optical communication system

10 ··· Raman amplifier

20 ··· transmitter

21 ··· S-band signal light source

22 ··· C-band signal light source

23 ··· L-band signal light source

24 ··· signal light multiplexer

30 ··· receiver

40 ··· optical fiber transmission line

100 ··· Raman amplification optical fiber

110 ··· optical fiber coil

120 ··· pumping light source

121 ··· S-band pumping light source

122 ··· C-band pumping light source

123 ··· L-band pumping light source

124 ··· pumping light multiplexer

130 ··· signal light source

140 ··· optical spectrum analyzer.

[Name of the Document] Abstract

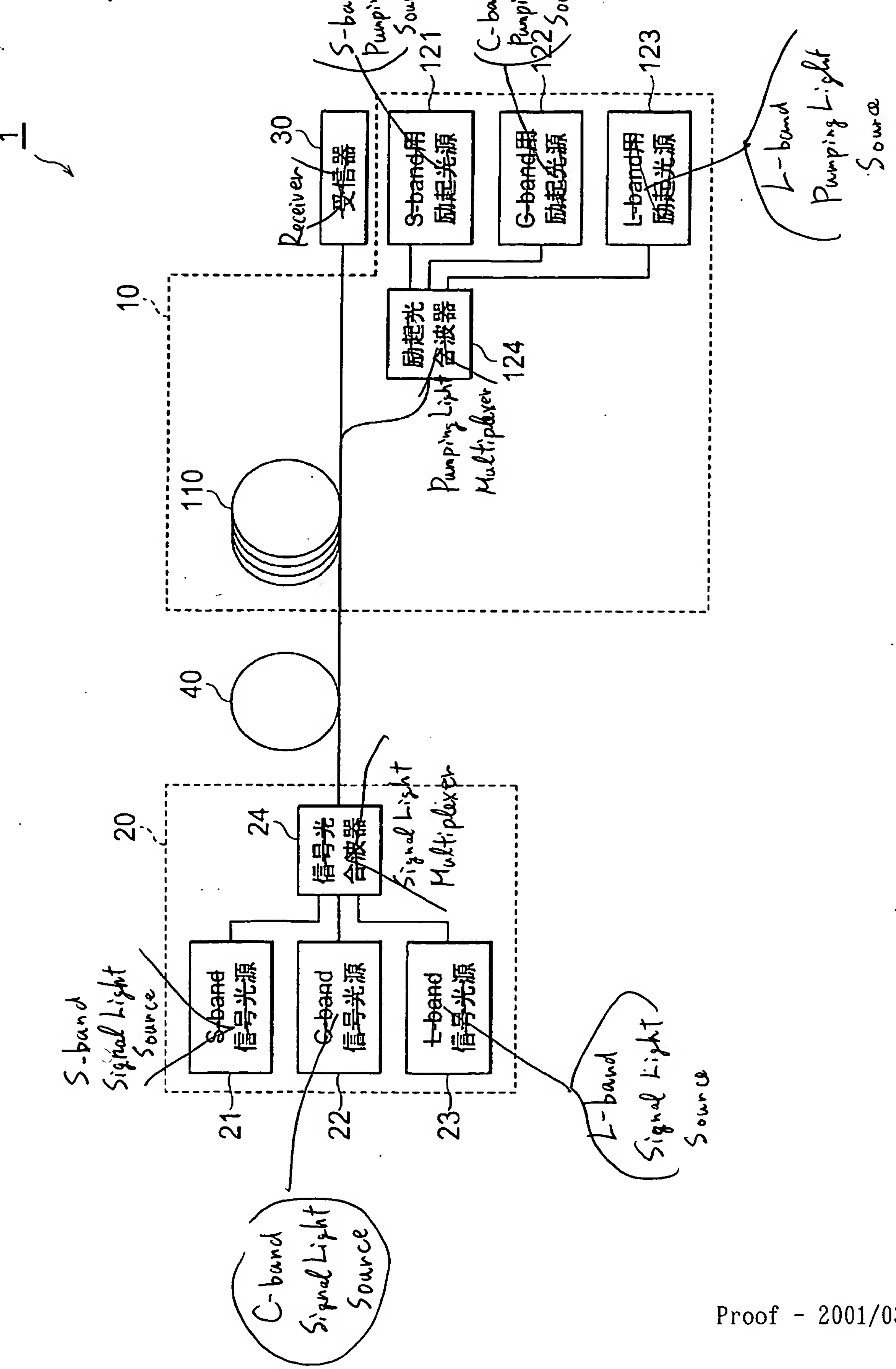
[Abstract]

[Problem] It is to provide a Raman amplification optical fiber and the like comprising a structure which can Raman-amplify signal light including a plurality of wavelength components at a high efficiency and effectively restrain signal waveforms from deteriorating due to influences of nonlinear optical phenomena, while improving the degree of freedom in the design of optical fiber transmission lines and Raman amplifiers.

[Solving Means] As characteristics at each wavelength of signal light, the Raman amplification optical fiber has a chromatic dispersion with an absolute value of 6 ps/nm/km or more but 20 ps/nm/km or less, and an effective area A_{eff} of 20 μm^2 or less, preferably less than 15 μm^2. More preferably, as a characteristic at each wavelength of signal light, the Raman amplification optical fiber has a Raman gain coefficient G_R/A_{eff} of 0.005 $(W\cdot m)^{-1}$ or more.

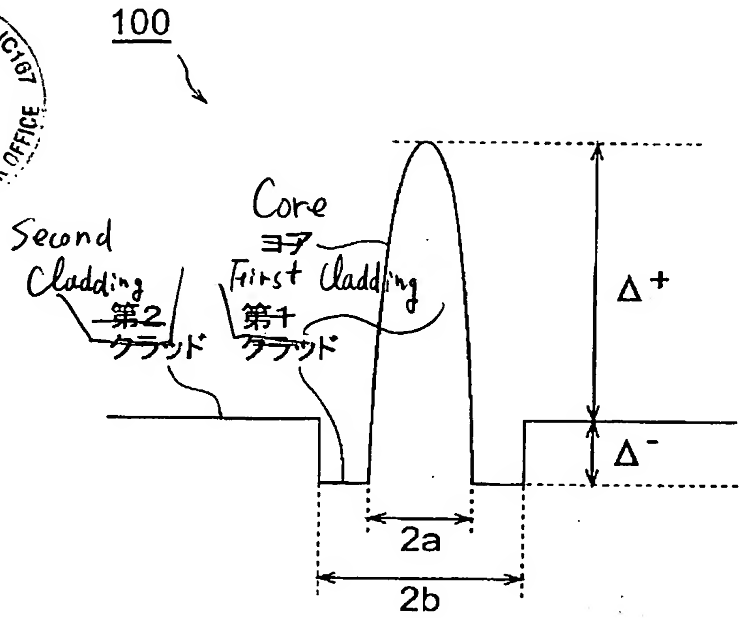
[Selected Drawing] Fig. 2

~~【図３】~~ [Fig.3]


1
10
20
30
~~受信器~~
Receiver
121
~~S-band用励起光源~~
S-band Pumping Light Source
122
~~C-band用励起光源~~
C-band Pumping Light Source
123
~~L-band用励起光源~~
L-band Pumping Light Source
124
~~励起光合波器~~
Pumping Light Multiplexer
110
40
24
~~信号光合波器~~
Signal Light Multiplexer
21
~~S-band信号光源~~
S-band Signal Light Source
22
~~C-band信号光源~~
C-band Signal Light Source
23
~~L-band信号光源~~
L-band Signal Light Source

~~【書類名】~~ ~~図面~~ [NAME OF DOCUMENT] Drawings

~~【図１】~~ [Fig. 1]



~~【図２】~~ [Fig. 2]